ENGINEERING TRIPOS PART IIA
MANUFACTURING ENGINEERING TRIPOS PART I

Wednesday 2 May 2007 9 to 10.30

ENGINEERING TRIPOS PART IIA: Module 3C2
MANUFACTURING ENGINEERING TRIPOS PART I: Paper P4B

MATERIALS PROCESS MODELLING AND FAILURE ANALYSIS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Engineering Tripos:
Single-sided script paper

Manufacturing Engineering Tripos:
20 page booklet, rough work pad

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

1. (a) In the context of the Rosenthal equations for heat flow in welding, explain what is meant by each of the following:

   (i) the thick plate solution;

   (ii) the "fast" limit.

What are the key assumptions used to derive the Rosenthal equations? [25%]

(b) A weld in a large carbon steel plate was found to be close to the safety limit associated with possible embrittlement due to martensite formation. A suggested remedy is the use of preheat to decrease the cooling rate after welding, and this is to be investigated using the Rosenthal equations.

For the weld concerned, the appropriate solution for the temperature history $T(t)$ at a position (y, z) from the weld line in a plane normal to the welding direction is

$$T(t) = T_o + \frac{(q/v)}{2\pi \lambda t} \exp\left(-\frac{y^2 + z^2}{4at} \right)$$

where T_o is the initial (uniform) temperature of the plate, taken to be 20°C,

(q/v) is the heat input per unit length of weld,

λ is the thermal conductivity of the steel,

a is the thermal diffusivity of the steel.

(i) Show that the peak temperature rise is given by

$$T_p - T_o = \frac{(q/v)}{(y^2 + z^2)} \left(\frac{2a}{e \pi \lambda} \right)$$ [20%]

(ii) For the modified weld, the steel plate is preheated to a temperature T_{ph} equal to 200°C. There must however be no change in the size of the fusion zone, the region for which $T_p \geq T_m$, where T_m is the melting point of the steel (equal to 1470°C). Derive an expression for the factor by which the heat input should be adjusted in the preheated weld, and find its value. [20%]

(cont.

(iii) The limit of the heat-affected zone (HAZ) is the boundary for which the peak temperature equals the A_1 temperature of the steel (equal to 723 °C). Evaluate the ratio of the HAZ sizes in the modified and original welds. [15%]

(iv) For positions in the HAZ for which the peak temperature is close to the melting point, the cooling curve for temperatures of 800°C and below is well-approximated by

$$T - T_0 = \frac{(q/v)}{2\pi\lambda t}.$$

Explain why this approximation is valid. Define what is meant by Δt_{8-5}, and use the approximate solution above to derive expressions for Δt_{8-5} for the original and the preheated welds. Hence evaluate the ratio of Δt_{8-5} for the two welds and comment on the result. [20%]

2. (a) Summarise the typical input data and predicted outputs for conventional numerical analyses of thermal and thermomechanical processes. What other data are required for these analyses to be useful industrially? Explain why microstructural models potentially add significant value to these analyses. Give examples of the application of models for microstructural evolution in the following situations:

(i) cogging deformation of cast Ni alloy ingots;

(ii) fatigue failure initiating from a weld in a steel oil rig structure. [70%]

(b) (i) Two steel plates were butt-welded together and the welded plate was flame-cut across the weld. It immediately failed by fast fracture with a crack running the length of the plates close to the weld line. Explain carefully why the failure occurred and suggest a remedy.

(ii) For another application, a second pair of steel plates is to be butt-welded and in service will be subject to fatigue loading normal to the weld line. How could the welds be treated to optimise the fatigue life? Explain your reasoning. [30%]

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3. Figure 1 shows a possible deformation mode for the plane strain compression of a wide rigid-plastic plate of thickness h between frictionless parallel dies of width b.

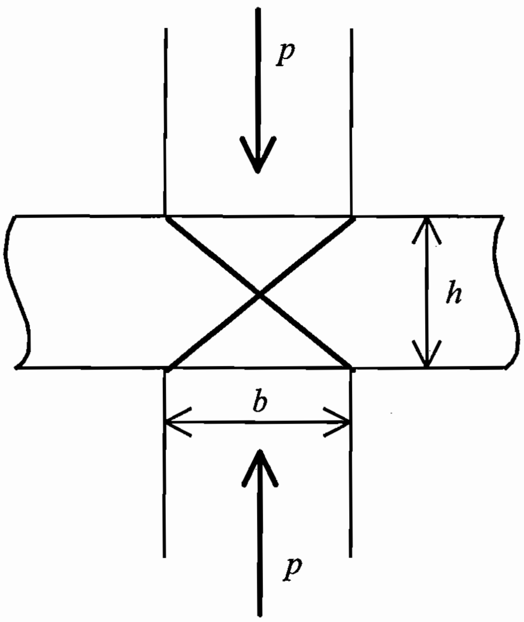

Figure 1

(a) Draw the corresponding hodograph and hence show that an upper bound solution for the die pressure p needed to cause yielding in the plate is

$$\frac{p}{2k} = \frac{1}{2}\left(\frac{h}{b} + \frac{b}{h}\right)$$

where k is the shear yield stress of the plate material. [40%]

(b) Sketch the variation of $p/2k$ predicted by this equation for $0 < h/b < 10$. In the limits $b >> h$ and $b << h$, $p/2k$ tends to lower values than are predicted by this equation. Explain why this is so, illustrating your answer with sketches of the deformation patterns. State the values of $p/2k$ in these limiting geometries. [40%]

(c) A wide steel plate is compressed between dies of width 10 mm. The yield stress of the dies is 1.5 times greater than that of the plate. Estimate the maximum thickness of plate which can be deformed plastically without the dies themselves yielding. [20%]

4. (a) A filament-wound GFRP pressure vessel was used for a cyclic process involving water being heated to 150°C under pressure, then the vessel being emptied and de-pressurised. The stress in the pressure vessel walls varied from 90 MPa under pressure to zero when empty. After a number of cycles the vessel began to leak. Suggest how and why the failure might have occurred and describe the nature of the damage. The coefficient of thermal expansion of epoxy is approximately 10 times greater than that of glass. [25%]

(b) A mild steel container made from spot-welded plates was used for storing scrap metal out-of-doors. It failed as a result of corrosion after being in use for only one year. Explain why corrosion might be expected to occur and where you would expect to find it in the container. What changes could have been made to ensure a longer lifetime, other than changing the material of the container? [25%]

(c) Some austenitic stainless steel bolts were to be used in a marine environment. Tests were conducted on the material to investigate its behaviour in this environment. Tensile specimens were subjected to various static loads and the time to failure was noted. Below a critical stress the lifetime was essentially infinite, though at higher stresses (still well below the yield stress of the material) the lifetime decreased rapidly. Explain these observations. Would you expect the design to remain safe if the stress in service remained below the critical value? [25%]

(d) A room-temperature pressure vessel made from high-strength steel was cleaned out using acid to remove some corrosion. When it was next pressurised the vessel exploded. Suggest the likely cause of the failure, explaining how the problem would have arisen. How could the failure have been prevented? [25%]

END OF PAPER

Module 3F1, April 2007 – SIGNALS AND SYSTEMS – Answers

1 (b) (i) $G(s) = \frac{1}{s(s+1)}$. Both systems are (marginally) unstable.

(ii) $k > 0$.

(c) (i)

$$|z| = \frac{\sqrt{1+2\sigma+\sigma^2+\omega^2}}{\sqrt{1-2\sigma+\sigma^2+\omega^2}}$$

2 (a) (i) $g_k = p^k$, $k = 0,1,2,\ldots$.

(ii) $y_k = \sum_{i=0}^{k} u_{k-i} g_i = \sum_{i=0}^{k} u_{k-i} p^i$

(b) (ii) $r_{XX}(t_1,t_2) = \frac{1}{3} r_{UU}(t_1,t_2)$. The random process is WSS.

3 (b) $\Phi_Y(u) = \Phi_{X_1}(u)\Phi_{X_2}(u)$.

(c) $\Phi_{X_1}(u) = \text{sinc}(ub_1/2)$, $\Phi_{X_2}(u) = \text{sinc}^2(ub_2/2)$, $\Phi_Y(u) = \text{sinc}(ub_1/2)\,\text{sinc}^2(ub_2/2)$.

4 (a) $P(A) = 0.8$, $P(B) = 0.1$, $P(C) = 0.1$.

(b) Efficiency $= 91.92\%$.

(c) $I(X_{n+1};X_n) = 0.1525$ and $H(X_{n+1}|X_n) = 0.7694$.